OCEAN AND CLIMATE STUDIES

Ocean scientists work aboard the U.S. research ship *Laurence M. Gould* in waters near the Antarctic Peninsula. *(NSF/USAP photo)*

Though it borders the world's major oceans, the Southern Ocean system is like no other in the world, with 4 times more water than the Gulf Stream and 400 times more than the Mississippi River. It is a sea where average temperatures do not reach 2°C in the summer, where even the water itself is so distinctive that it can be identified thousands of miles away in currents that originated here. These Antarctic Bottom Waters provide the major source of cooling for the world's oceans. In fact, if the Earth is a heat engine, Antarctica should be viewed as its circulatory cooling component.

The climate in Antarctica is also unique, linked as it is to the extreme conditions of the land and sea below the troposphere (the inner region of the atmosphere, up to between 11 and 16 kilometers). This ocean/atmosphere environment defines and constrains the marine biosphere and in turn has a dynamic relationship with the global ocean and with weather all over the planet. Few major energy exchanges on Earth can be calculated without factoring in these essential antarctic phenomena. As such, they are both an indicator and a component of climate change.

The Ocean and Climate Studies program sponsors research that will improve understanding of the high-latitude ocean environment, including the global exchange of heat, salt, water, and trace elements; there is also an emphasis on sea-ice dynamics, as well as the dynamic behavior and atmospheric chemistry of the troposphere. Major program elements include the following:

- **Physical oceanography:** The dynamics and kinematics of the polar oceans; the interaction of such forces as wind, solar radiation, and heat exchange; water-mass production and modification processes; ocean dynamics at the pack-ice edge; and the effect of polynyas on ventilation.

- **Chemical oceanography:** The chemical composition of sea water and its global differentiation; reactions among chemical elements and compounds in the ocean; fluxes of material, within ocean basins and at their boundaries; and the use of chemical tracers to map oceanic processes across a range of temporal and spatial scales.

- **Sea-ice dynamics:** The material characteristics of sea ice, from the level of the individual crystal to the large-scale patterns of freezing, deformation, and melting.
- **Meteorology:** Atmospheric circulation systems and dynamics, including the energy budget; atmospheric chemistry; transport of atmospheric contaminants to the antarctic; and the role of large and mesoscale systems in the global exchange of heat, momentum, and trace constituents.

Solar radiation processes on the east antarctic plateau.
Stephen G. Warren and Thomas Grenfell, University of Washington.

This project is an experimental study of solar radiation processes near the surface at Dome C, the French-Italian station in East Antarctica. It will be carried out in cooperation with the Laboratoire de Glaciologie et Geophysique de l'Environment in Grenoble, France. The emphasis will be on the reflection of sunlight by snow and the transmission of sunlight through clouds. The observations we gather will be relevant to climate, remote sensing, and the physics of ice and snow.

We will measure transmissions of solar radiation through clouds, and these measurements will be used to obtain effective cloud optical depths to estimate cloud radiative forcing, with applications in climate models. We will develop a method to obtain this information from pyranometers alone so that the historical record of solar radiation observations in the antarctic interior can be analyzed for climatological information on clouds.

Observations of the angular pattern of solar radiation reflected from the snow surface will allow us to validate information from satellite-derived atmospheric profiles. Using radiative transfer modeling through the atmosphere, we will reconcile measured surface reflection functions with the empirical functions obtained from advanced Vidicon high-resolution radiometers on the polar orbiting satellites of the National Oceanic and Atmospheric Administration.

Finally, the spectral peak of snow albedo will be accurately located in order to resolve a discrepancy over the spectral absorption of pure ice in the visible to near-ultraviolet range. (OO-201-O; NSF/OPP 00-03826)

Antarctic Meteorological Research Center (AMRC).
Charles R. Stearns and George Weidner, University of Wisconsin-Madison.

The Antarctic Meteorological Research Center (AMRC) was created in 1992 to improve access to meteorological data from the Antarctic. The AMRC's mission is to conduct research in observational meteorology and the stewardship of meteorological data, along with providing data and expert assistance to the antarctic community to support research and operations. The AMRC plans to fulfill its mission by

- continuing to maintain and expand, as appropriate, the long-term record of all meteorological data on Antarctica and the adjacent Southern Ocean, and make these data available to the scientific community for multidisciplinary use (special attention will be given to obtaining data not normally or readily available by other means);

- continuing to generate satellite products, specifically but not limited to antarctic composite imagery, and expand and improve on them as much as possible;
- conducting research in observational meteorology, especially with regard to climatological analyses and case studies; and
- continuing to conduct and expand, as appropriate, educational and public outreach activities associated with antarctic meteorology and related fields

Using available meteorological interactive processing software and other standard computing tools, we will collect data from all available sources for processing, archiving, and distribution.

The mission of the AMRC not only includes the opportunity to advance the knowledge of antarctic meteorology, but with the free availability of its data holdings, the AMRC gives others the opportunity to advance the frontiers of all antarctic science. Continuing educational outreach activities on meteorology and the Antarctic, an important component of this work, have the potential to raise the science literacy of the general public, as well as the level of K-12 science education. (OO-202-O; NSF/OPP 01-26262)

Atmospheric oxygen variability in relation to annual-to-decadal variations in terrestrial and marine ecosystems.
Ralph F. Keeling, Scripps Institution of Oceanography.

Oxygen, the most abundant element on Earth, comprises about a fifth of the atmosphere. But much of the Earth's oxygen resides in other chemical species (in water, rocks, and minerals) and, of course, in the flora and fauna that recycle it (both directly and as carbon dioxide) through photosynthesis and respiration. Thus, scientists are interested in measuring the concentration of molecular oxygen and carbon dioxide in air samples; our project includes a subset of sample collections being made at a series of baseline sites around the world.

These data should help improve estimates of the processes whereby oxygen is cycled throughout the global ecosystem, specifically through photosynthesis and atmospheric mixing rates, and also improve predictions of the net exchange rates of carbon dioxide with biota, on land and in the oceans. An important part of the measurement program entails developing absolute standards for oxygen-in-air in order to ensure stable long-term calibration. In addition, we are conducting surveys of the oxidative oxygen/carbon ratios of both terrestrial- and marine-based organic carbon, hoping to improve the quantitative basis for linking the geochemical cycles of oxygen and carbon dioxide.

These results should help enhance our understanding of the processes that regulate the buildup of carbon dioxide in the atmosphere and of the change processes, especially climate change, that regulate ecological functions on land and in the sea. (OO-204-O; NSF/OPP 95-Okeel)

Validation of the Atmospheric Infrared Sounder (AIRS) over the antarctic plateau.
Von Walden, University of Idaho.

The antarctic plateau is an ideal ground site for calibrating and validating infrared satellite instruments. In terms of surface temperature and emissivity, the large continental ice sheet is one of the most homogeneous land surfaces on Earth. Ground-based measurements of upwelling infrared radiation between 8 and 12 micrometers are very nearly equal to those measured by satellites because of the minimal atmospheric emission and absorption found on the antarctic plateau. Therefore, accurate measurements of spectral infrared radiance made at the surface there can provide data to validate the National Aeronautics and Space Administration's (NASA's) Atmospheric Infrared Sounder (AIRS).

In our fieldwork at Dome Concordia, we will use the polar atmospheric emitted radiance interferometer (PAERI) to measure upwelling and downwelling spectral infrared radiance. In addition, an infrared thermometer will map changes in surface radiation at spatial scales similar to the ground footprint of AIRS. Radiosondes will be launched to obtain temperature and humidity profiles. A ground-based global positioning system unit will attempt to measure the extremely low values of total precipitable water (about 1 millimeter in the summer). The zenith and azimuth of the PAERI viewing angle will be adjusted to match the AIRS viewing angle of the surface and through the atmosphere.

The measurements and data we gather will help validate the AIRS and contribute to the growing body of knowledge about spectral infrared radiance. (OO-213-M; NASA grant)

Mesoscale, seasonal, and interannual variability of surface-water carbon dioxide in the Drake Passage.
Taro Takahashi and Colm Sweeney, Lamont-Doherty Earth Observatory, Columbia University.

The Southern Ocean provides an important component of the global carbon budget. Cold surface temperatures, with consequent low vertical stability, ice formation, and high winds, produce a very active environment where the atmospheric and oceanic reservoirs readily exchange gaseous carbon. The Drake Passage is the narrowest point through which the Antarctic Circumpolar Current and its associated fronts must pass; this so-called chokepoint provides the most efficient site to measure the latitudinal gradients of gas exchange.

Working from the R/V *Laurence M. Gould*, we will use equipment designed to measure both dissolved carbon dioxide and occasional total carbon dioxide in the surface waters during transects of the Drake Passage. This work extends similar measurements made aboard R/V *Nathaniel B. Palmer* and complements other data collected on surface temperatures and currents. These several data sets, supplemented by satellite imagery, will enable scientists to estimate the net production and carbon export by the biological community, as well as the basic targets-a quantitative description of the sources of dissolved carbon dioxide variability and a calculation of carbon dioxide fluxes between the ocean and the atmosphere. (OO-214-O; NSF/OPP 00-03609)

AnSlope, Cross-slope exchanges at the Antarctic Slope Front.
Arnold Gordon, Stanley Jacobs, and Martin Visbeck, Lamont-Doherty Earth Observatory, Columbia University.

What is the role of the antarctic slope front (ASF) and continental slope morphology in the exchanges of mass, heat, and freshwater between the shelf and oceanic regimes, in particular those leading to outflows of dense water into intermediate and deep layers of the adjacent deep basins and world ocean circulation?

The importance to the global ocean circulation and climate of cold water masses originating in the Antarctic is understood, but the processes by which these water masses enter the deep ocean circulation are not. Our program, called AnSlope, will address this problem. Our primary goal is to identify the principal physical processes that govern the transfer of shelf-modified dense water into intermediate and deep layers of the adjacent deep ocean, as well as understand the compensatory poleward flow of waters from the oceanic regime. The upper continental slope is the critical gateway for the exchange of shelf and deep ocean waters. Here the topography, velocity, and density fields associated with the nearly ubiquitous ASF must strongly influence the transfer of water properties between the shelf and oceanic regimes.

AnSlope has four specific objectives:

- determine the ASF's mean structure and the principal scales of spatial and temporal variability, and estimate the ASF's role in cross-slope exchanges and mixing of adjacent water masses;
- determine the influence of slope topography on frontal location and outflow of dense shelf water;
- establish the role of frontal instabilities, benthic boundary layer transports, tides, and other oscillatory processes on cross-slope advection and fluxes; and
- assess the effect of shear-driven and double-diffusive mixing, lateral mixing identified through intrusions, and nonlinearities in the equation of state on the rate of descent and the fate of outflowing, near-freezing shelf water.

We will address these objectives with an integrated observational and modeling program. We will perform a set of measurements whose basic elements are moorings, microstructure analysis, tracers, and basic tidal modeling. Three cruises over a 12- to 14-month period beginning in the austral summer of 2003 will provide the data. Moorings will be in place throughout this period. Existing Italian and German programs will provide enhancement and a test bed for our parameterizations of cross-front exchange. (OO-215-O; NSF/OPP 01-25172)

Measurements and improved parameterization of the thermal conductivity and heat flow through first-year sea ice.
Hajo Eicken and Martin Jeffries, University of Alaska-Fairbanks.

The sea-ice cover in the polar oceans strongly modifies ocean-atmosphere heat transfer. Most important, the ice cover thermally insulates the ocean, with sea-ice thermal conductivity determining the magnitude of the heat flow for a given ice temperature gradient. Despite its importance (second only to ice albedo), our knowledge of sea-ice thermal conductivity is limited to highly idealized models developed several decades ago. General circulation models (GCMs) and large-scale sea-ice models currently include overly simplistic parameterizations of ice thermal conductivity that are likely to contribute significantly to errors in estimating ice production rates.

We will carry out a set of field measurements from which the thermal conductivity of first-year sea ice will be derived as a function of ice microstructure, temperature, salinity, and other parameters. Measurements will be carried out by letting thermistor arrays freeze into the fast ice of McMurdo Sound, which represents an ideal natural laboratory for this type of measurement. To minimize errors and identify the most robust technique, we will collaborate with colleagues from New Zealand and compare different methodologies for measurement and analysis. We will also assess the impact of ice microstructure (spatial distribution of brine, crystal sizes) and convective processes on the effective rate of heat transfer.

Antarctic data will be compared with arctic thermal conductivity data sets to assess regional contrasts and the impact of different physical processes on heat flow and to arrive at a comprehensive, improved parameterization of ice thermal conductivity for large-scale simulations and GCMs. This component of the work will involve ice-growth modeling and collaboration with the Sea-Ice Model Intercomparison Project Team established under the auspices of the World Climate Research Program. This research will advance and improve

- our understanding of the processes and parameters controlling heat transfer and the thermal conductivity of first-year sea ice,

- techniques for deriving thermal conductivity and heat flow data from thermistor arrays,
- our understanding of sea-ice processes and heat flow through the ice cover in McMurdo Sound,
- parameterizations of thermal conductivity for use in large-scale and high-resolution one-dimensional simulations, and
- the representation of first-year ice thermal properties (both antarctic and arctic) in GCMs. (OO-253-O; NSF/OPP 01-26007)

South Pole monitoring for climate change: Amundsen-Scott South Pole Station.
David Hofmann, Climate Monitoring and Diagnostics Laboratory, National Oceanic and Atmospheric Administration, South Pole Station.

The National Oceanic and Atmospheric Administration has been conducting studies to determine and assess the long-term buildup of trace atmospheric constituents that influence climate change and the ozone layer. Time-series analyses of long-term data provide insight into several phenomena of particular interest, including

- seasonal and temporal variations in greenhouse gases,
- the depletion of stratospheric ozone,
- transantarctic transport and deposition,
- the interplay of the trace gases and aerosols with solar and terrestrial radiation fluxes that occur on the polar plateau, and
- the development of polar stratospheric clouds over Antarctica.

Project scientists measure carbon dioxide, methane, carbon monoxide, stable isotopic ratios of carbon dioxide and methane, aerosols, halocarbons, and other trace constituents. Flask samples are collected and returned for analysis, while concurrent in situ measurements of carbon dioxide, nitrous oxide, selected halocarbons, aerosols, solar and terrestrial radiation, water vapor, surface and stratospheric ozone, wind, pressure, air and snow temperatures, and atmospheric moisture are made. Air samples are also collected at Palmer Station.

These measurements allow us to determine the rates at which concentrations of these atmospheric constituents change; they also point to likely sources, sinks, and budgets. We collaborate with climate modelers and diagnosticians to explore how the rates of change for these parameters affect climate. (OO-257-O; NSF/OPP 90-17842)

Drake Passage high-density XBT/XCDT Program.
Janet Sprintall, Scripps Institution of Oceanography.

During each crossing of the research ship *Laurence M. Gould*, we intend to launch expendable bathythermographs (XBTs), supplemented by expendable conductivity-depth-temperature (XCDT) probes, to obtain high-density sections from which to study the seasonal variability and long-term change in the upper ocean structure of the Drake Passage, which is off the tip of South America. Whenever the distance between Antarctica and neighboring land is narrow, as in the Drake Passage and the area off the Cape of Good Hope, the Antarctic Circumpolar Current, which drives the waters in the Southern Ocean, is extremely strong.

The information we gather will lead to the establishment of a high-quality database that can be used to study the magnitude and depth of penetration of the seasonal signals, the connections to atmospheric forcing, and the effects of interannual variations such as those associated with the Antarctic Circumpolar Wave.

The sections obtained during these voyages will supplement the approximately 20 sections that we have been gathering and studying since September 1996. Our continuing data analysis will be carried out in cooperation with the Argentine Antarctic Institute in Buenos Aires. (OO-260-O; NSF/OPP 00-03618)

Collection of atmospheric air for the NOAA/CMDL worldwide flask sampling network, Palmer Station.
David Hofmann, Climate Monitoring and Diagnostics Laboratory, National Oceanic and Atmospheric Administration, Palmer Station.

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- seasonal and temporal variations in greenhouse gases,
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Personnel at Palmer Station collect air samples to be analyzed for carbon dioxide, methane, carbon monoxide, and stable isotopic ratios of carbon dioxide and methane. Flasks are also collected for analysis of halocarbons, nitrous oxide, and other trace constituents.

These measurements allow us to determine the rates at which concentrations of these atmospheric constituents change; they also point to likely sources, sinks, and budgets. We collaborate with climate modelers and diagnosticians to explore how the rates of change for these parameters affect climate. (OO-264-S; NSF/OPP ASA-0037)

Operation of an aerosol sampling system at Palmer Station.
Colin G. Sanderson, Environmental Measurements Laboratory, U.S. Department of Energy.

Radionuclides, some of which occur naturally in the surface air, are atoms emitting radioactive energy. It is these, as well as nuclear fallout and any accidental releases of radioactivity, that the Environmental Measurements Laboratory's (EML's) Remote Atmospheric Measurements Program (RAMP) is designed to detect and monitor. Since 1963, EML, as part of the U.S. Department of Energy, has run the Global Sampling Network to monitor surface air. The RAMP system provides on-site analysis in 13 different locations around the world, including Palmer Station. Using a high-volume aerosol sampler, a gamma ray spectrometer, and a link to the National Oceanic and Atmospheric Administration's ARGOS satellite system, we continue sampling air at Palmer Station for anthropogenic radionuclides. (OO-275-O; NSF/OPP no number)

Antarctic automatic weather station program: 2001-2004.
Charles Stearns and George Weidner, University of Wisconsin-Madison.

A network of nearly 50 automatic weather stations (AWS) has been established on the antarctic continent and several surrounding islands. These facilities were built to measure surface wind, pressure, temperature, and humidity. Some of them also track other atmospheric variables, such as snow accumulation and incident solar radiation.

Their data are transmitted via satellite to a number of ground stations and put to several uses, including operational weather forecasting, accumulation of climatological records, general research, and specific support of the U.S. Antarctic Program, especially the Long-Term Ecological Research program at McMurdo and Palmer Stations. The AWS network has grown from a small-scale program in 1980 into a significant, extremely reliable data retrieval system that has proven indispensable for both forecasting and research. This project maintains and augments the AWS as necessary. (OO-283-M/S; NSF/OPP 00-88058)

Measurement of combustion effluent carbonaceous aerosols in the McMurdo Dry Valleys.
Anthony D. Hansen, Magee Scientific Company.

Though Antarctica remains comparatively pristine, there is heightened awareness of the impact the human presence and scientific work being undertaken there could have. To continue a series of assessments of the long-term environmental impact of the U.S. Antarctic Program's operations, we plan to generate a database detailing the abundance of carbonaceous aerosols ("black carbon") in the McMurdo Dry Valleys.

The Long-Term Ecological Research (LTER) study site in the McMurdo Dry Valleys supports a fragile, nutrient-limited ecosystem that could be significantly affected by human activities. Of special concern are deposits of particles from black carbon. These could result from the exhaust of diesel powered generators and helicopter operations in the McMurdo Dry Valleys; it is even possible that combustion products from McMurdo Station, about 100 kilometers away, could migrate to the study area. For three austral summers, we are deploying a real-time optical analyzer at the LTER site to measure the concentration of black carbon, polycyclic aromatic hydrocarbons, and other filterable organic compounds useful in fingerprinting combustion products. (OO-314-O; NSF/OPP 98-15140)

Shipboard acoustic doppler current profiling on the R/V *Nathaniel B. Palmer* and *Lawrence M. Gould*.
Teresa K. Chereskin, Scripps Institution of Oceanography, and Edward Firing, University of Hawaii.

Currents in the Southern Ocean have a profound influence on the world's oceans-and therefore on global temperature and the planet's ecosystem-yet some remote regions receive little scientific attention. This project is using doppler technology (sound-wave transmission and reflection) to explore the velocities of upper ocean currents. We are building a quality-controlled data set in one such sparsely sampled and remote region that nonetheless appears to play a significant role in global ocean circulation. We will develop and maintain a shipboard acoustic doppler current profiler program on board the R/V *Nathaniel B. Palmer* and *Laurence M. Gould*.

Part of our long-term goal is to characterize the temporal and spatial velocity structure in the Southern Ocean. This entails measuring the seasonal and annual changes in upper ocean currents in the Drake Passage and then combining this information with similar temperature observations to see how the heat exchange varies and how it drives upper ocean currents. (OO-317-L; OO-315-N; NSF/OPP 98-16226)